Observations of convective cooling in the tropical tropopause layer in AIRS data

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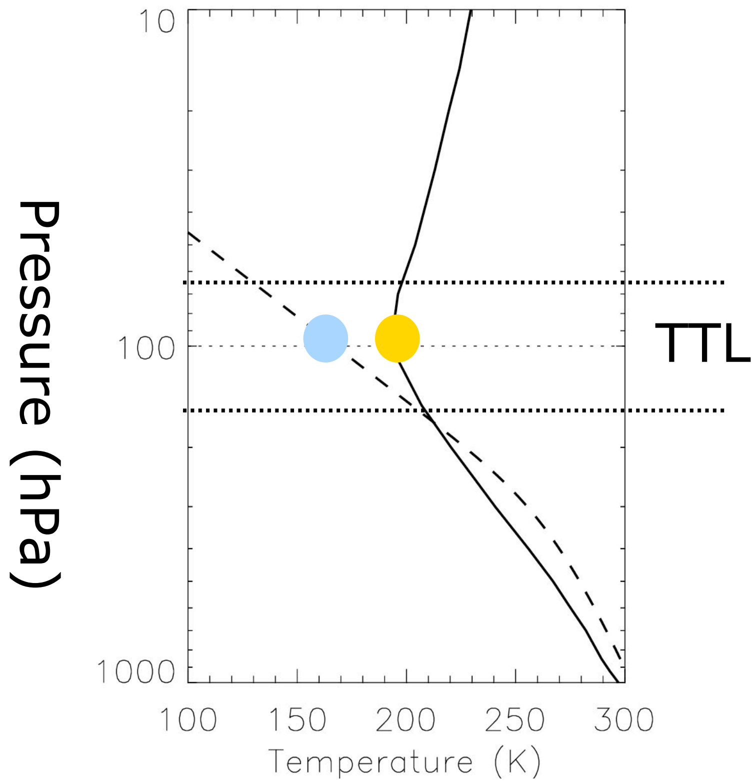
Convective impact in the Tropical Tropopause Layer



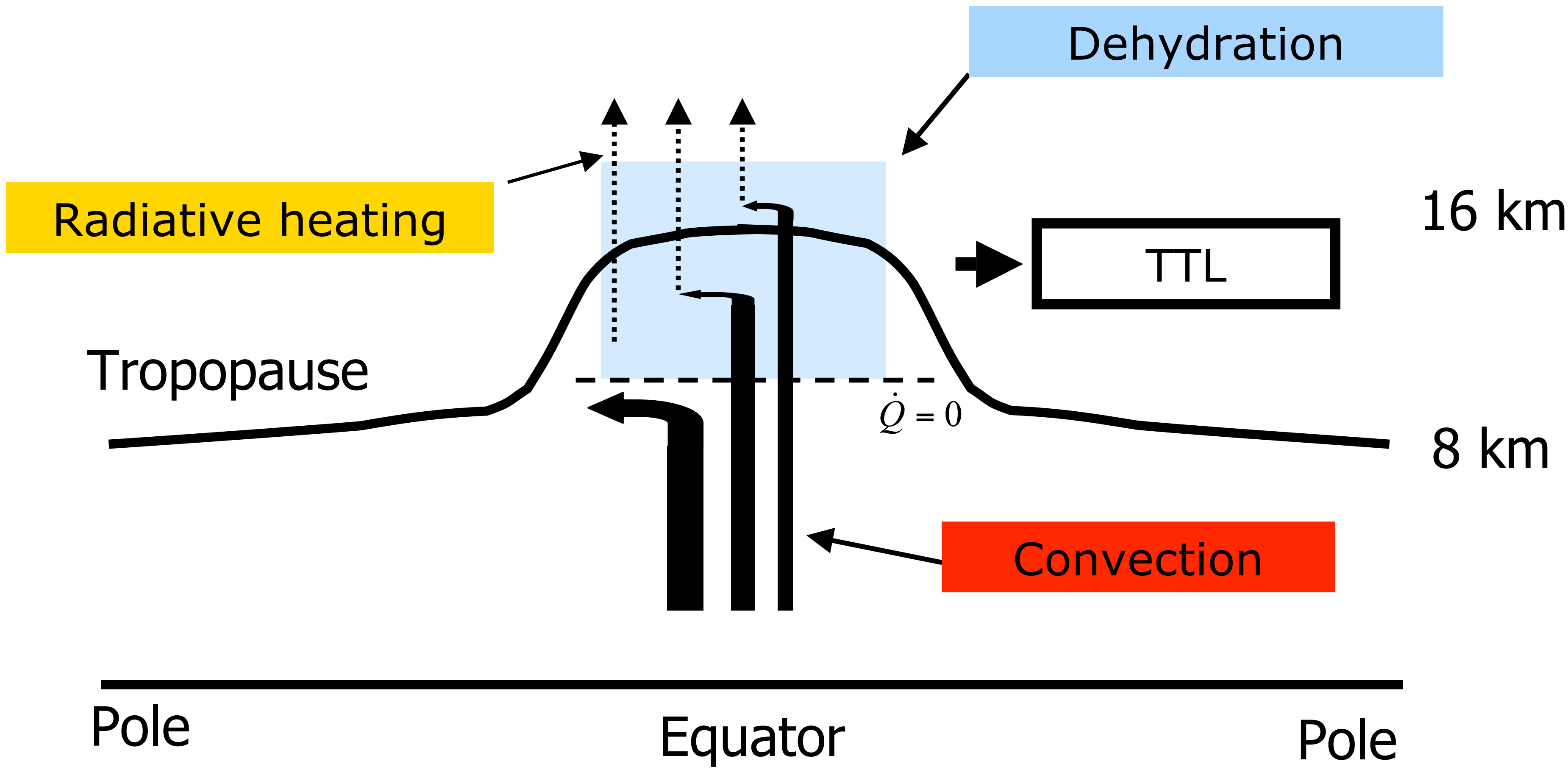
T = 192K

$[H_2O]$ = 4.52 ppmv

T = 165K

$[H_2O]$ = 0.024 ppmv

Tropical tropopause layer



Data (1)

- AIRS (Atmospheric Infrared Sounder)

  - Level 2 temperature profile
  - Horizontal resolution/coverage : 50 km/Global
  - Vertical resolution : 28 levels (1100 - 0.1mb)
  - Temporal resolution : 2/day
  - Error : < 1 K
  - Ocean only
  - Feb. 2003 and Jul. 2003

Data (2)

- NCEP/AWS Infrared Global Geostationary Composite

  - Global composite images from four weather satellites in geosynchronous orbit
    (GMS, GOES-East, GOES-West, Meteosat)
  - 11 micron Brightness Temperature
  - Horizontal resolution/coverage : 14 km/Global
  - Temporal resolution : 48/day
  - Feb. 2003 and Jul. 2003

Methodology

- Local monthly mean temperature profiles for 1°x1 ° boxes (AIRS)
- Individual temperature anomalies (AIRS)

$$\Delta T_i(lon, lat, t, z) = T_i(lon, lat, t, z) - T_{mean}(lon, lat, z)$$

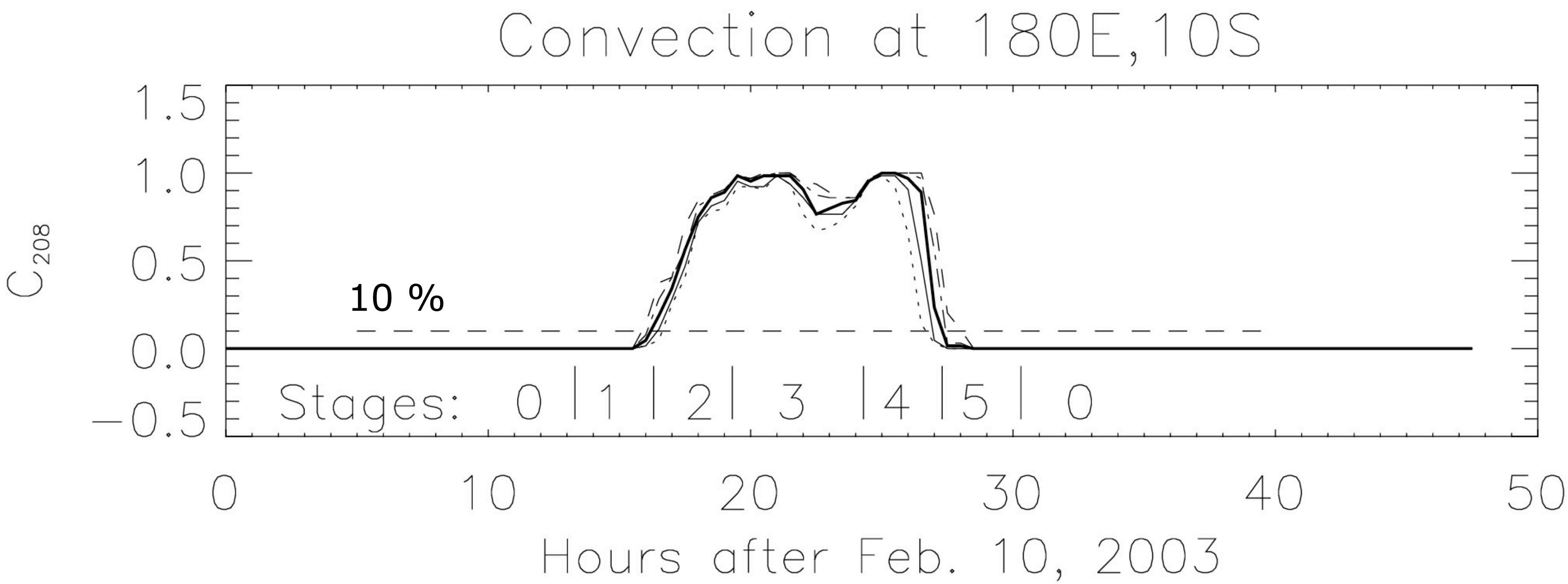
- Assigning convective stage for each temperature anomalies using NCEP/AWS IR image.
- Averaging temperature anomalies according to their convective stages

$$\Delta T(z) = \frac{1}{n} \sum_{lon,lat,t} \Delta T_i(lon, lat, t, z)$$

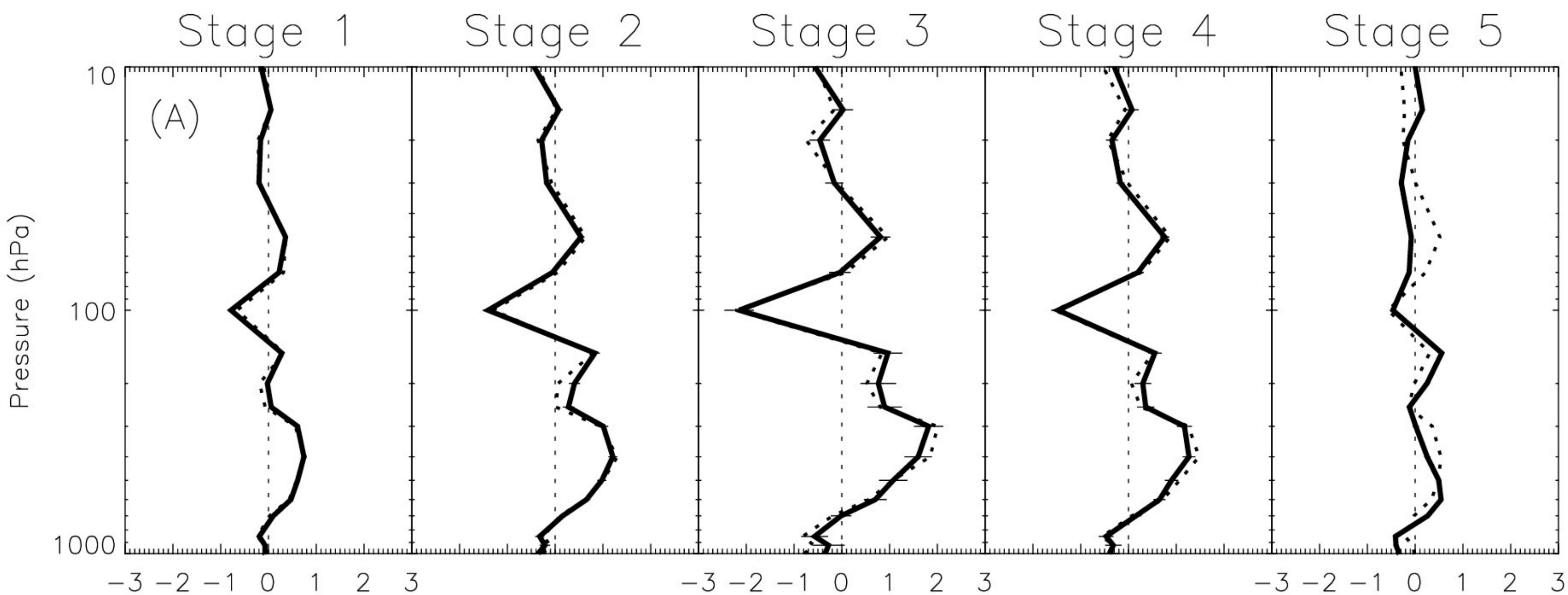
For convective stages 0,1,…,5

Convective stages

- C_{208} :the fraction of pixels in a box with brightness temperatures below 208K (NCEP/AWS IR image)

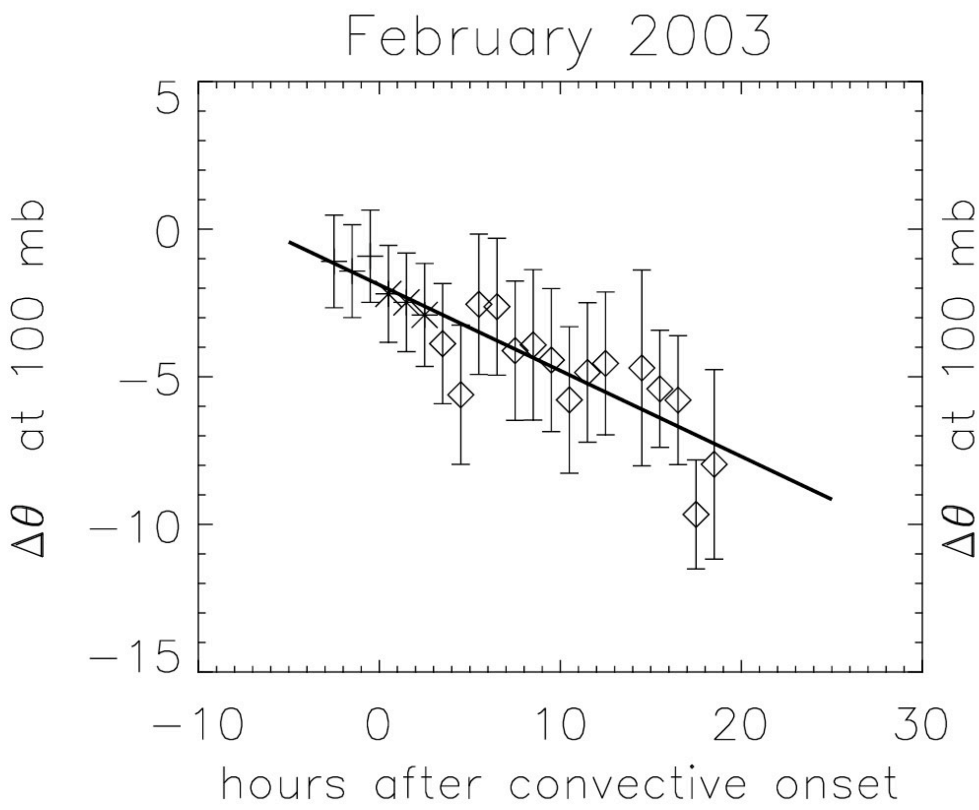


Mean temperature anomaly profile



(Feb. 2003)

Cooling rate



- Cooling rate = -7 K/day

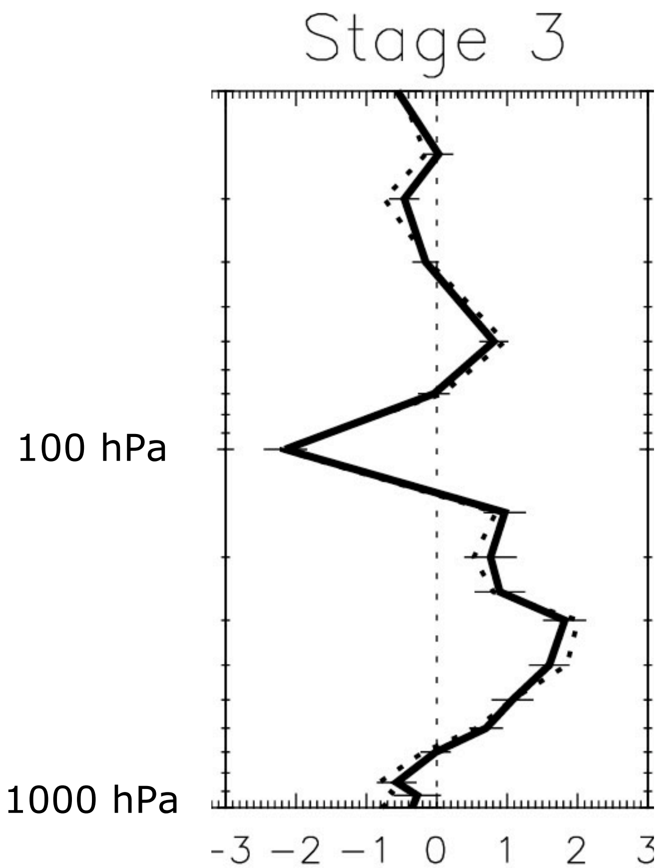
Tropopause cooling

- Adiabatic lifting
  - Cold point analysis shows the tropopause moves downward during active convection → diabatic component

- Cloud-top radiative cooling
  - No diurnal cycle in cooling amount
    (Net cloud cooling = in-cloud cooling + solar heating)

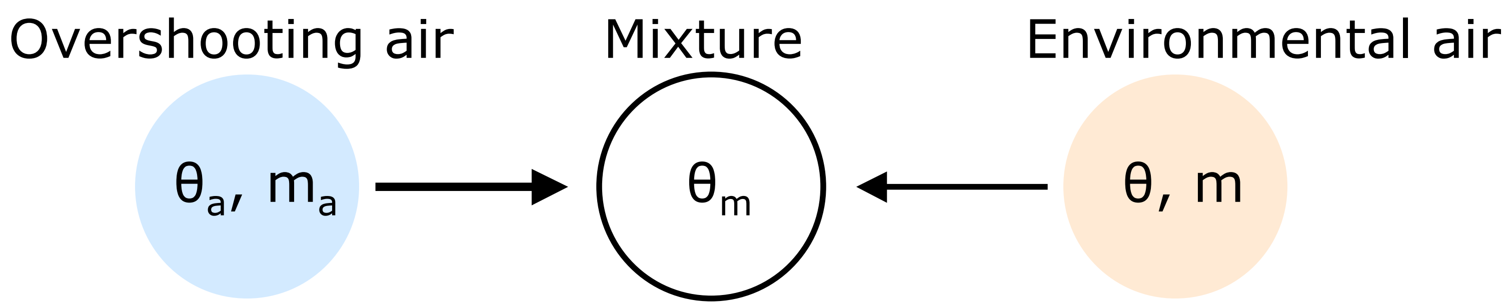
- Turbulent mixing of overshooting air

Radiative cooling? – diurnal separation



- Net cloud-top cooling = in-cloud cooling + solar heating

Turbulent mixing of overshooting cloud



$$\theta_m = f \cdot \theta_a + (1-f)\cdot\theta \quad \text{where } f = \frac{m_a}{m_a + m}$$

Cooling rate : $Q = \dfrac{d\theta_m}{dt} = \dfrac{df}{dt}\cdot(\theta_a - \theta)$

$$\frac{df}{dt} = \frac{Q}{\theta_a - \theta} = \frac{-7K/day}{355K - 375K} = 0.35/day$$ (for one convective event)

In tropical average:

0.35/day * 3% = 1.05 %/day

→ ~3 months turnover time

Conclusion

- This study shows a clear signal of cooling near the tropical tropopause during active convection.

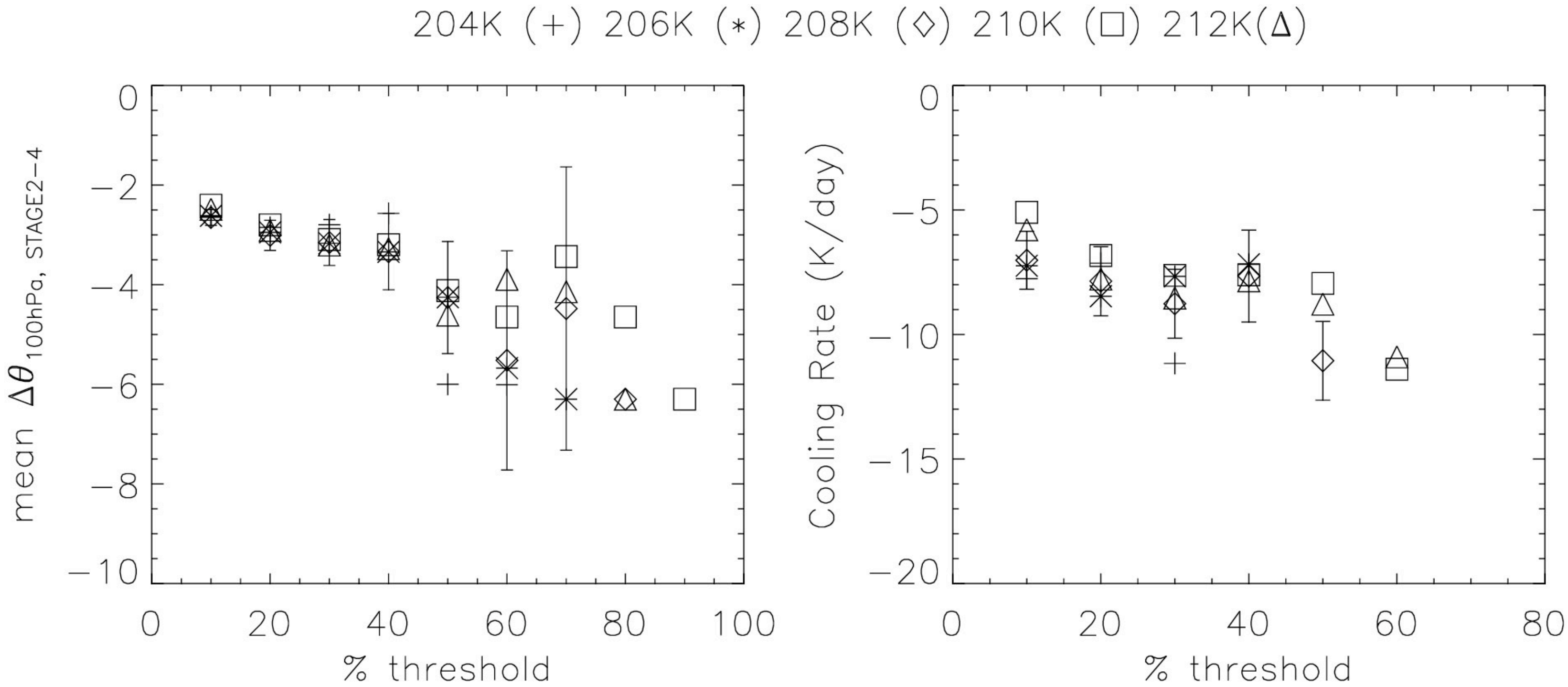
- Estimated cooling rate is –7 K/day.

- This tropopause cooling during active convection cannot be explained by cloud-top radiative cooling. We suggest that mixing of overshooting air with its environment can possibly contribute to this cooling.

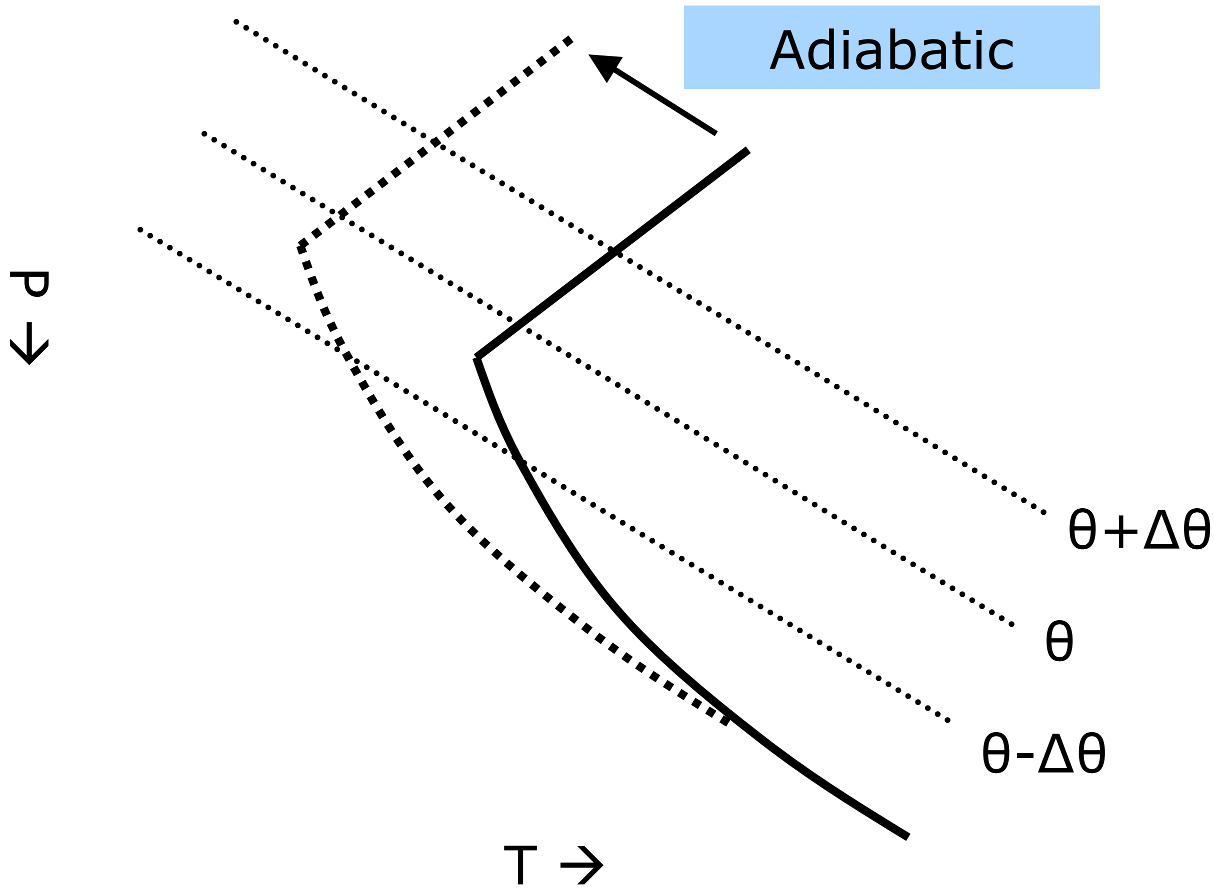
Overshooting convective cloud

The End

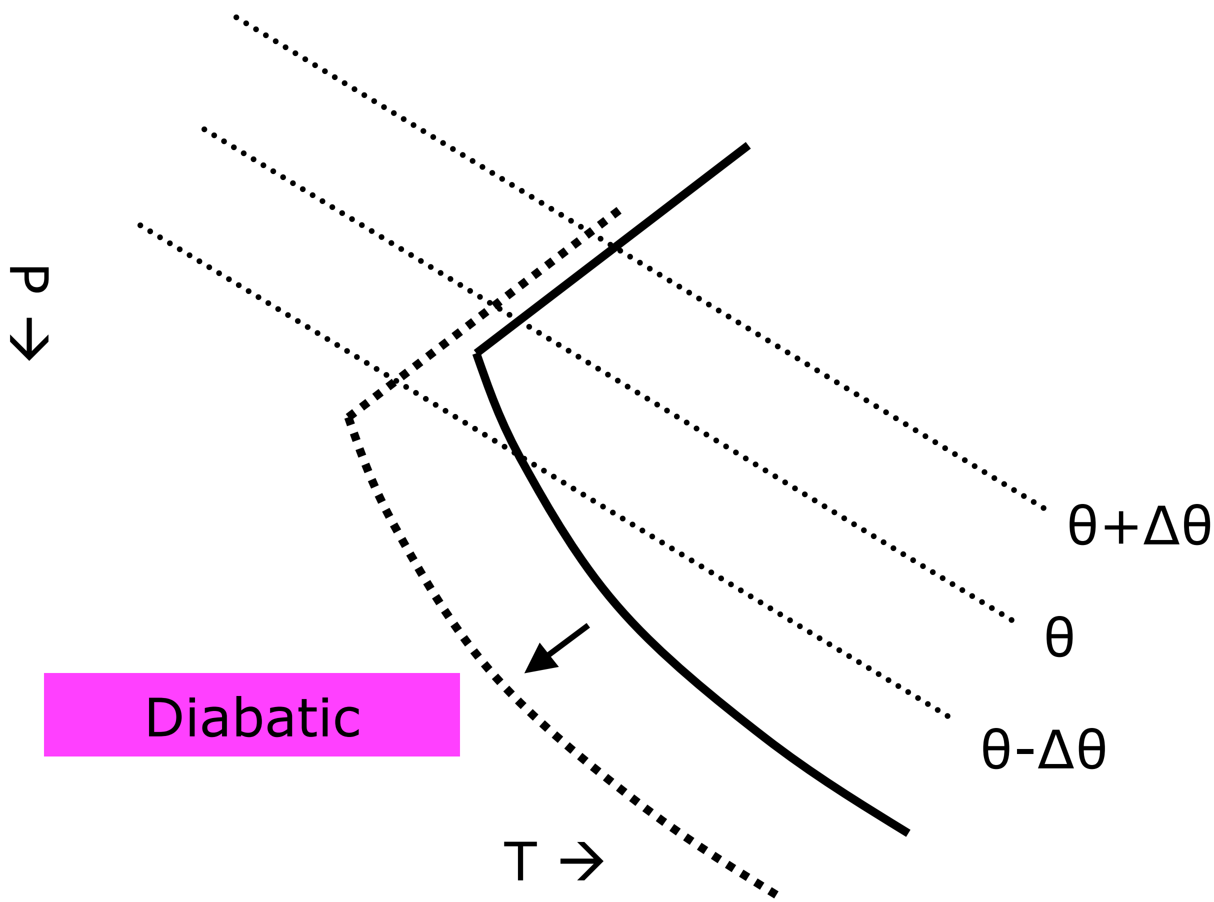
Sensitivity test



Adiabatic lifting?



Adiabatic lifting?



Cloud-top radiative cooling?(Ackerman et al, 1988)

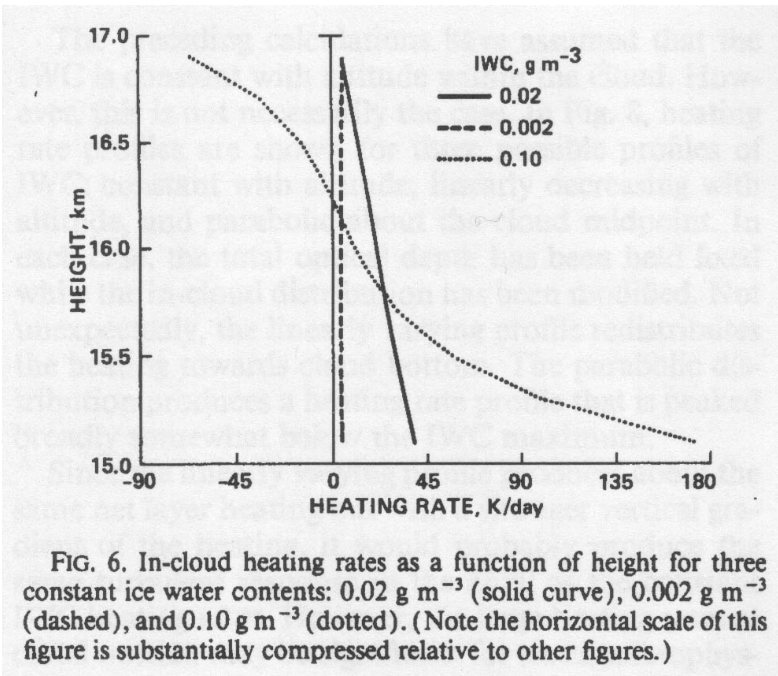


FIG. 6. In-cloud heating rates as a function of height for three constant ice water contents: 0.02 g m^{-3} (solid curve), 0.002 g m^{-3} (dashed), and 0.10 g m^{-3} (dotted). (Note the horizontal scale of this figure is substantially compressed relative to other figures.)

In-cloud heating

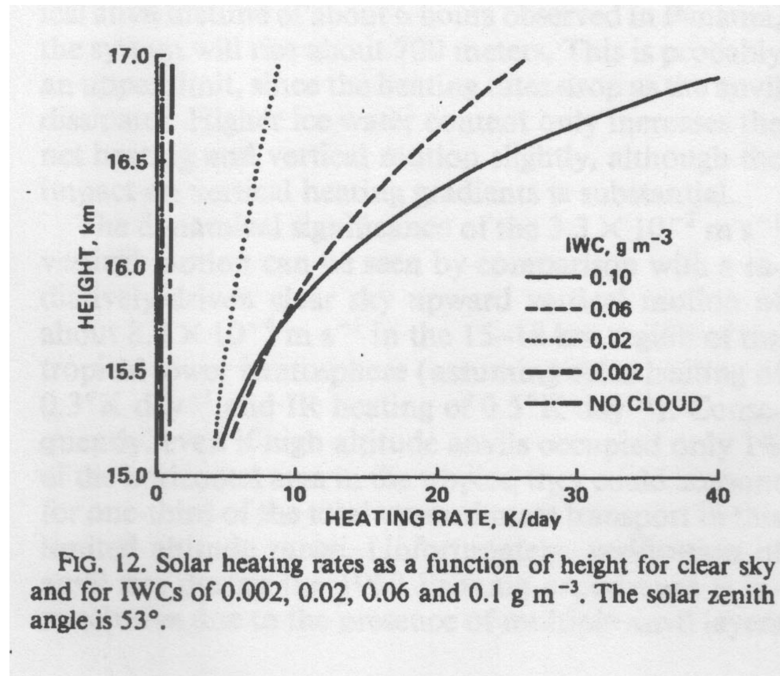
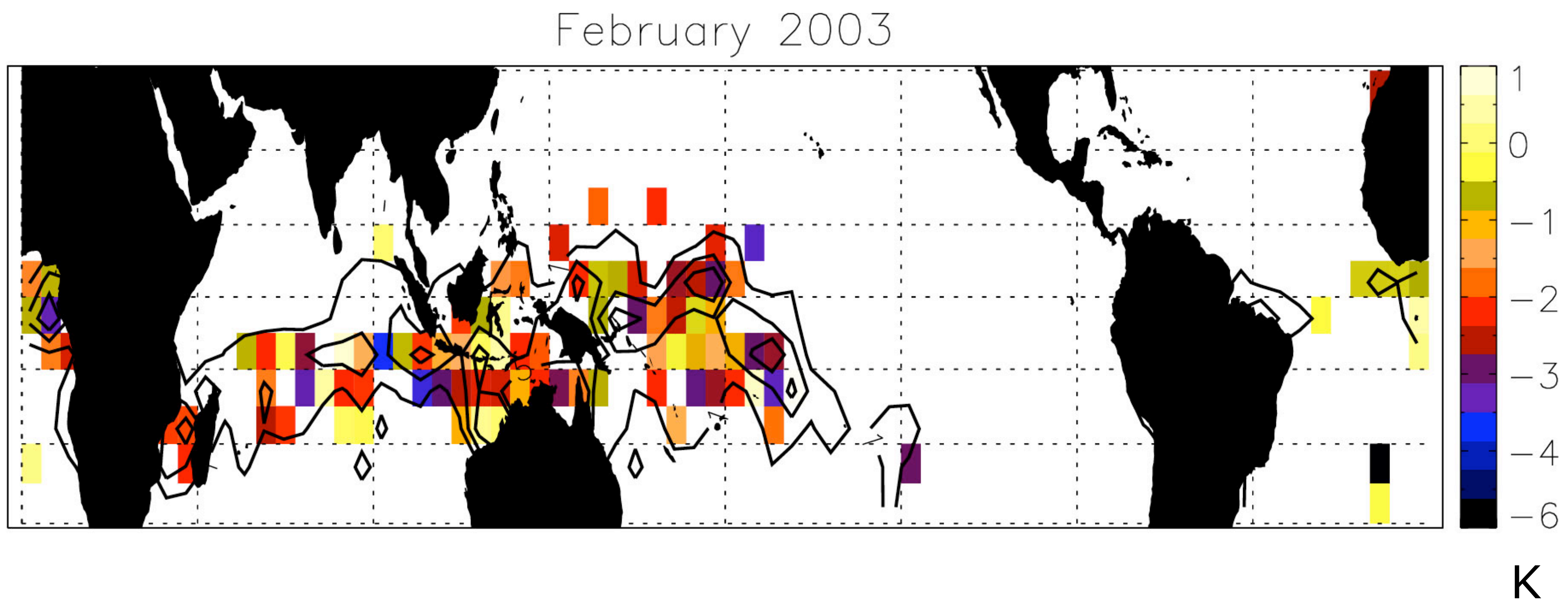


FIG. 12. Solar heating rates as a function of height for clear sky and for IWCs of 0.002, 0.02, 0.06 and 0.1 g m^{-3}. The solar zenith angle is 53°.

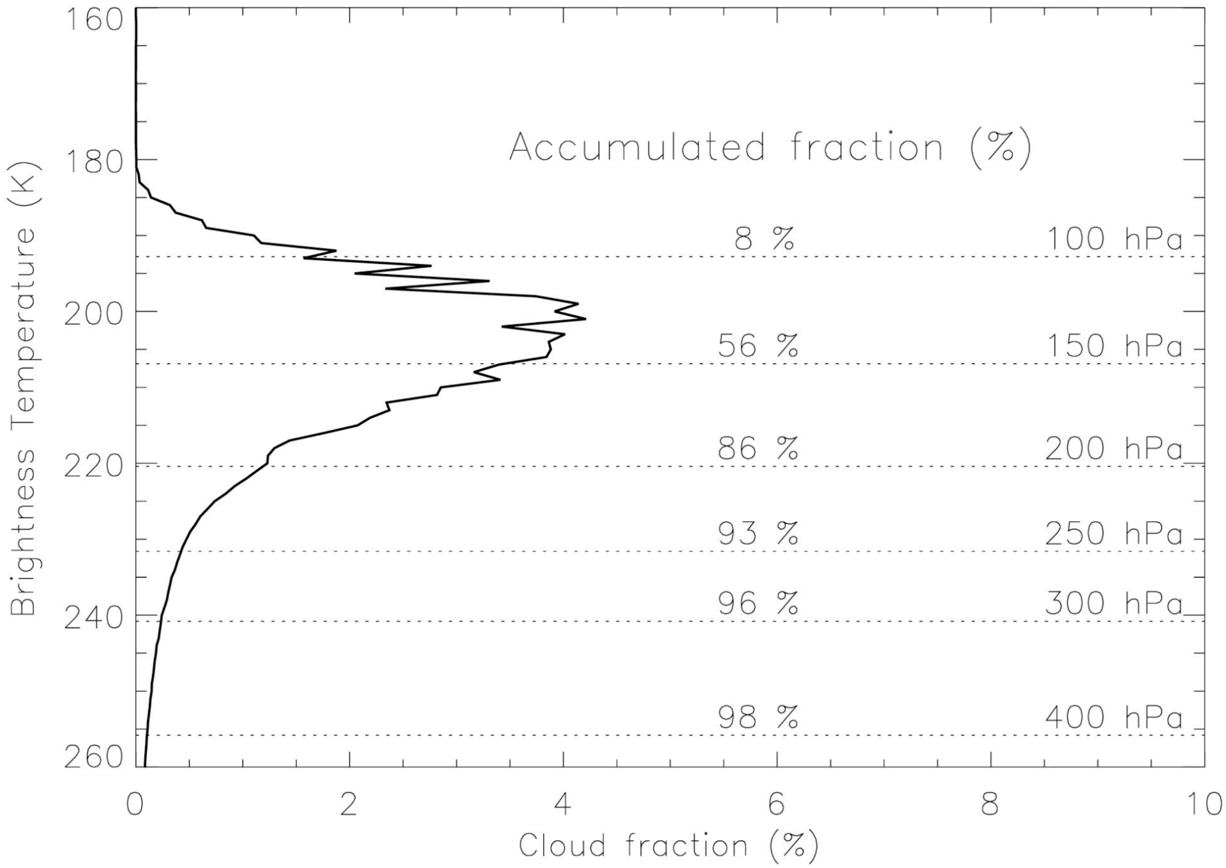
Solar heating

- Net cloud-top heating = in-cloud heating + solar heating

Cooling at 100 hPa (Potential temperature anomaly)



Cloud-top cooing? - T_b distribution



- Cloud fraction to cause –7 k/day → 70%